AD

BRL

TECHNICAL NOTE NO. 1703

AN INSTRUMENTED RANGE MEETING THE REQUIREMENTS OF
A WOUND BALLISTICS SMALL ARMS PROGRAM

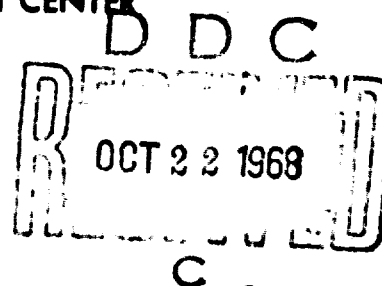by

William J. Bruchey, Jr.
Larry M. Sturdivan

September 1968

U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

DDC
OCT 2 2 1968
C

23

BALLISTIC RESEARCH LABORATORIES

TECHNICAL NOTE NO. 1703

SEPTEMBER 1968

AN INSTRUMENTED RANGE MEETING THE REQUIREMENTS OF A WOUND BALLISTICS SMALL ARMS PROGRAM

William J. Bruchey, Jr.
Larry M. Sturdivan

Terminal Ballistics Laboratory

ABERDEEN PROVING GROUND, MARYLAND

PAGES_____

ARE

MISSING

IN

ORIGINAL

DOCUMENT

BALLISTIC RESEARCH LABORATORIES

TECHNICAL NOTE NO. 1703

WJBruchey,Jr./LMSturdivan/mew
Aberdeen Proving Ground, Md.
September 1968

AN INSTRUMENTED RANGE MEETING THE REQUIREMENTS OF A WOUND BALLISTICS SMALL ARMS PROGRAM

ABSTRACT

Instrumentation, equipment, and space requirements are outlined
which would satisfy a portion of the needs of the Wound Ballistics Program
of research into the terminal behavior of missiles from a variety of
antipersonnel munitions (fragments, flechettes, bullets, etc.).

TABLE OF CONTENTS

I. INTRODUCTION

In the early to mid 1950's a program was initiated by the newly formed Wound Ballistics project to assess the effects of bullets on biological systems. As a spin-stablilized missile is a complicated dynamic physical system, it was thought that much insight into the behavior of a projectile could be gained by studying the behavior of the projectile in tissue simulant models such as water or 20 percent gelatin. Out of these early studies grew the rather extensive studies of gelatin tissue-simulants presently conducted at Biophysics Laboratory, Edgewood Arsenal,[1] and the gelatin X-ray studies at Terminal Ballistics Laboratory of the Ballistic Research Laboratories, Aberdeen Proving Ground.[2]

The test firings of projectiles at Biophysics Laboratory consist, at present, of firing a variety of bullets at several velocities through barrels of appropriate twist to achieve the desired aerodynamic stability. The velocities at which the bullets are fired roughly correspond to the velocities with which one would find the bullet traveling at several ranges between 10 and 500 m if launched from a conventional weapon at nominally standard conditions. Gelatin blocks are placed at about 10 m (± 2 m) from the weapon. Exact distance of placement is determined by the aerodynamics of the bullet and the approximate striking yaw that is desired. That is, the block is positioned so that the bullet will strike while in the low, medium or high yaw portion of its yawing cycle. For yaws larger than those naturally occurring in the cycle a yaw inducer is used. The yaw inducer is a modified flash suppressor which produces asymetrical gas flow about the projectile as it exits the muzzle; thus producing a larger than normal yaw.

The loss of kinetic energy in the gelatin block between 1 and 15 cm penetration is measured by a high-speed movie camera. The block is backlighted with a high intensity light source collimated through a Fresnel lens. The outline of a high-speed projectile is never visible, however, since the deformed gelatin acts as a lens which scatters the light going through it. What is actually measured is the displacement versus time of the tip of the cavity that the projectile creates as it

7

traverses the block. If the projectile is a bullet similar high-speed cameras record the yaw of the bullet as it approaches the block. Three dimensional yaw is obtained from orthogonal views of the bullet in a mirror system.

A similar program of tissue simulant tests is followed in Terminal Ballistics Laboratory. However, the displacement as a function of time, striking velocity, and striking yaw are obtained from multiple-flash, orthogonal, X-ray pictures of the projectile just before and during penetration of the gelatin. The yaw of the projectile within the gelatin may be observed from these pictures as the gelatin has a negligible refractive index for X rays.

II. DISCUSSION

Current techniques employed by the Terminal Ballistics Laboratory of the Ballistic Research Laboratories, Aberdeen Proving Ground and the Biophysics Laboratory, Edgewood Arsenal to measure the kinematic performance of missiles are limited in their application in both relatively long-term research projects and short-term, "ad hoc" studies. The systems on the whole are subject to the following restrictions.

- Both systems are limited by the complexity of the procedure as to the number of firings which they will yield per unit time. This is of prime importance to the "ad hoc" type study which requires answers in the least amount of time but still requires large numbers of experimental samples.

- The complexity of the systems requires the use of a large number of personnel and quantity of equipment.

- The equipment used requires extensive space.

A system is proposed for an instrumented Wound Ballistics Range which would require a multiple microflash stroboscope, a large format still camera, a ballistic pendulum, and a gas gun to study the loss of kinetic energy of missiles penetrating a biological or simulated biological target. A brief description of the components is given in Appendixes A, B, and C. Each of the three major components of this sytem offers the following distinct advantages over the currently used systems.

8

- The strobe-camera system requires a shorter setup time between firings. The strobe has a recycling time of a few seconds and the film plate can be changed in the same period of time. The greatest time savings is realized by the use of a Polaroid auxiliary camera. Both of the currently used systems require firings to determine if the event recorders are properly synchronized with the missile time of flight. For each of these tests time must be taken to develop the film. The Polaroid film needs only 10 sec to develop and could be used throughout the test firings to insure that the synchronization is not lost during a series of firing which would result in little or no usable data.

- Large numbers of firings to measure the loss of kinetic energy of the missile as a function of striking conditions may be made at low cost thus freeing the more elaborate equipment for the firings where more complete data are needed.

- More accurate determination of the line of flight can be made since the sequence of missile images is on one sheet of film and the multiple flashes are from a single tube. Line of flight measurement, over a distance of 6 to 24 in., is not contingent upon alignment between frames on a strip of film or alignment of a series of flash X-ray tubes as in present systems.

- Presently available strobe units are capable of producing 200,000 to 300,000 beam candlepower which is sufficient to provide reflective lighting of the projectile which neither of the other systems offer. This capability provides a means to measure the rotational velocity of a missile just prior to its striking the target.

- Projectile orientation and velocity at the air-target interface could be measured very accurately, within 1 percent, because a sequence of 10 to 15 values of these parameters would be available prior to entrance of the missile into the target. This number of values is not available in the present systems because of the upper limit on framing rate of the light cameras and inability to multiple flash a single X-ray tube.

- Chronographs now used could be eliminated.

The present multiple-flash, X-ray system and the high-speed motion picture studies of missiles traversing a target material rely on visual interpretation of photographic records of events taking place within the target to determine loss of energy. In gelatin studies by high-speed motion pictures the refractive index of the gelatin precludes direct

9

observation of the missile, thus velocity must be inferred from the position of the tip of the temporary cavity (the cavity momentarily created by the bullet) on sequential frames of the film. As loss of mass or change of shape cannot be observed, it cannot be adjusted for in the loss in energy calculation. On the other hand, the assumption that the mass and shape of the bullet remain constant causes underestimation of the amount of energy deposited in the target. The same problem arises to a certain extent with the X-ray system because the velocity is inferred from the displacement of the missile as a function of time and thus knowledge of the mass of each portion of fragmented missile is required to calculate loss of energy.

The use of a ballistic pendulum to measure the energy deposited in the target does not require a measurement of the displacement time of the missile in the target. The energy deposited may be calculated by application of the principles of conservation of energy and momentum and knowledge of the striking energy of the missile and maximum excursion of the pendulum from its equilibrium position. Because this system allows calculation of the destructive kinetic energy transmitted into the target without having to "see" through the target, it is adaptable to acceptance of a wide variety of targets; i.e., excised animal tissues or organs, tissues or tissue simulants with clothing and/or body armor, etc.

While the high-speed, repetitive-flash system and the ballistic pendulum will produce the desired accuracy of measurement of the kinematic variables, the effectiveness of the system is dependent primarily on the ability to produce a desired set of initial conditions. These initial conditions are produced by the missile launching system. Presently for all bullet studies and most fragment studies the projectiles are launched using a modified rifle-cartridge system. It is proposed for this range that a new type system be constructed to launch the

10

projectiles by means of compressed gas. This type of system offers many advantages over the rifle-cartridge system. They are:

- A more constant velocity is obtained round-to-round. The missile velocity is directly proportional to the chamber pressure. In the rifle-cartridge system, this pressure is dependent upon the quantity of propellant, propellant distribution within the case, burning rate of the propellant, and chamber temperature. In the gas rifle system these variables are eliminated because the pressure chamber has constant volume and the pressure may be selected and monitored before each firing.

- A missile carrier (sabot), which would launch the projectile by pushing it through the barrel, would allow the pre-positioning of the missile in any desired launch orientation to insure a reproducible set of striking conditions.

- The perturbing effect of exhaust gases on the missile at the muzzle would be eliminated by the use of a gas release system as outlined in Appendix C. This would allow the placement of the muzzle within inches of the target to insure a controlled set of striking conditions.

- A separate gun is not required for each missile type. Only a few interchangeable barrels would be required.

III. CONCLUSIONS

Initial feasibility studies of the total system outlined herein could be undertaken with equipment currently available within the Ballistic Research Laboratories-Biophysics complex. The photographic equipment, cameras and stroboscope, are available at the Ballistic Research Laboratories for use. A small gas gun is available from Biophysics Laboratory. The projectile launcher would require only the machining of barrel extensions incorpor ing t gas release ports and sabot deflector. The existing barrel could then be modified to make them compatible with the barrel extensions to cons ct a prototype system.

Currently, the Wound Ballistics Group possesses a 5-wire pendulum (designed and tested by Interior Ballistics Laboratory of the Ballistic Research Laboratories) which was used in the lethality studies for the Silent Weapon System. With the allocation of a firing range (approximately 10 m), the entire system could be erected at Terminal Ballistics Laboratory within a minimum time with maximum output per dollar invested.

Because of the simplicity of the overall system there would be substantial savings in operating costs and personnel requirement relative to the present systems. Using the best available estimates the savings expected from the use of an operating system of this type is listed in the following table.

PROJECTED SAVINGS OF THE PROPOSED SYSTEM
VS
CURRENTLY USED RECORDING METHODS

RECORDING TECHNIQUES	MULTIPLE FLASH X-RAY	HIGH SPEED MOTION PICTURE	PENDULUM
PERSONNEL REQUIRED	4	6	3
% SAVINGS OF PERSONNEL COMPARED TO: X-RAY MOTION PICTURE.	25 % 50 %		
AVERAGE FIRING TIME PER ROUND	30 MIN.	20 MIN.	10 MIN.
% SAVING OF TIME COMPARED TO: X-RAY MOTION PICTURE	67 % 50 %		
% NET SAVINGS IN MANHOURS COMPARED TO: X-RAY MOTION PICTURE	75 % 75 %		

13

REFERENCES

1. Wound Ballistics Annual Progress Report, January-December 1964, CRDLR-3290, July 1965, (SECRET).

2. C. Grabarek, and L. Herr, "X-ray Multi-Flash System for the Measurement of Projectile Performance at the Target," Ballistic Research Laboratories Technical Note No. 1634, September 1966.

APPENDIX A

MULTIPLE-MICROFLASH SYSTEM

This system uses a stroboscopic light source to provide light pulses at a controlled pulse interval which permits exposures at known time intervals to be recorded on a single photographic plate. The photographic plate then provides a basis for quantitative studies of an event. For example, when distances are scaled on the photographic plate and the distance-time relationships are measured, the velocity and acceleration can be determined.

Presently, stroboscopic units are available which emit 1 μsec pulses at a controlled pulse interval. These units emit a peak light of 200,000 horizontal candle-power at a flash repetition rate from 25 to 100,000 cps. This provides ample light for reflective lighting of the impact of a high velocity bullet on gelatin. At the higher repetition rates reflective lighting also would permit the measurement of the angular velocity of a bullet as it strikes the target. An example of a commercially available unit is shown in Figure A-1.

The photographic plates used could be either the standard photographic plates used in large format still cameras or P/N Polaroid film. Sheet film offers the advantage of not requiring an enlargement of the negative. The P/N Polaroid film produces a positive print and negative in 10 sec. This offers the advantage of very small development time compared to the sheet film. The disadvantage of Polaroid film is that it may be necessary to enlarge the negative before extracting the data, in which case there may be some loss of resolution. If this loss of resolution was significant, sheet film would be used with the Polaroid camera being used as an auxiliary to insure that useful data was being collected from each firing. The actual choice of camera and film would be determined during the initial testing of the instrumented range.

15

MODEL 502

MULTIPLE MICROFLASH

MULTIPLE EXPOSURE PHOTOGRAPHY
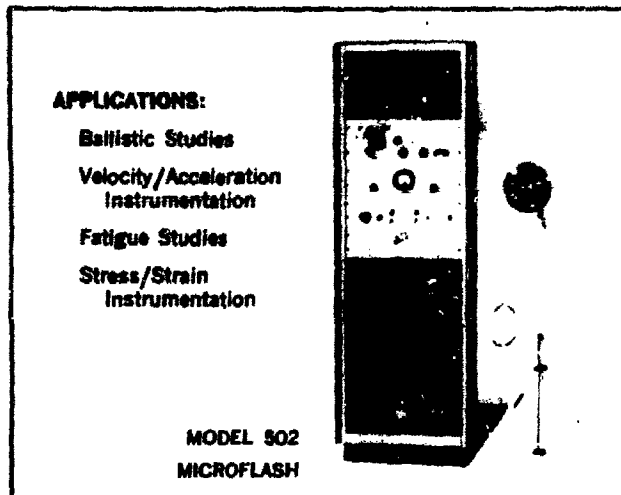
APPLICATIONS:

Ballistic Studies

Velocity/Acceleration
Instrumentation

Fatigue Studies

Stress/Strain
Instrumentation

MODEL 502
MICROFLASH

SPECIFICATIONS

Light Output:

The 502 multiflash can be used with either the FX-2 or the FX-3 flash tube. The FX-2 flash tube is approximately ½ inch square. It is used with an adjustable 8 inch parabolic reflector that has a reflective factor between 7-20 so that the 200,000 peak horizontal candle power (nominal) can be varied between 1.4×10^4 and 4.0×10^4 beam candle power (nominal). The FX-3 flash tube is a 3 inch line source that is used with a cylindrical reflector with a 180° beam pattern. It emits about 300,000 beam candle power (nominal).

Flash Duration:	1 Microsecond
Peak Light:	200,000 horizontal-candle-power (nominal)
Energy Input per Flash:	1.5 watt-seconds
Time Delay Between Flashes:	Variable from 10 microseconds to 40 milliseconds
Flash Repetition Rate:	from 25 cycles to 100,000 cycles
Triggering:	By microphone, electrical signal or by manual contact
Expected Flashtube Life:	10^5 flashes
Power Input:	115 ac/60 cycle
Power Supply:	10 KV dc
Dimensions:	24" wide x 69" high x 26" deep
Weight:	(15 unit system) approximately 150 lbs.

Figure A-1

APPENDIX B

THE BALLISTIC PENDULUM

The ballistic pendulum is a device used for measuring the velocity of a projectile or the momentum imparted to the pendulum by the projectile. From the wound ballistics viewpoint, the latter case is of interest since the momentum of the pendulum is used in calculating the energy deposited in the gelatin target by the bullet.

A sketch of the pendulum is shown in Figure B-1. In this type of pendulum, the bullet is fired into a 6-inch cube of gelatin mounted on the pendulum. The momentum of the pendulum immediately after the collision equals the momentum imparted by the projectile passing through the gelatin target. Since the mass of the platform and gelatin block is of much greater mass than the projectile, the velocity of the pendulum is much less than that of the bullet and is, therefore, easier to measure.

The equation for the energy deposited by the projectile may be determined by considering it to have a mass, M_1, traveling with a velocity, V_1, which strikes the pendulum, imparting to the pendulum a momentum, $M_4 V_4$, and exiting with a mass, M_3, and velocity, V_3. Since the collision time is very small compared to the time of swing of the pendulum, the supporting wires remain vertical during this time. Hence no external horizontal forces act on the system during the collision.

Let P = momentum

    Q = energy deposited in the gelatin target by the projectile

    T = kinetic energy

Subscripts

    1 = projectile before the collision

    3 = projectile after the collision

    4 = pendulum after the collision

17

Since energy and momentum are conserved;

$$P_1 = P_3 + P_4$$

$$Q = T_1 - T_3 - T_4$$

$$Q = T_1 - T_4 - \frac{(P_1 - P_4)^2}{2M_3}$$

$$Q = T_1 - T_4 - \frac{(M_1^2 V_1^2 + M_4^2 V_4^2 - 2M_1 M_4 V_1 V_4)}{2M_3}$$

$$Q = T_1 - T_4 - \frac{M_1}{M_3} T_1 - \frac{M_4}{M_3} T_4 + \frac{2(M_1 M_4 T_1 T_4)^{1/2}}{M_3}$$

For the case of non-fragmenting missiles;

$$M_1 = M_3$$

Therefore
$$Q = 2\left(\frac{M_4}{M_1} T_1 T_4\right)^{1/2} - T_4\left(1 + \frac{M_4}{M_1}\right) \qquad (B-1)$$

This is the basic equation used in determining the energy deposit of a projectile. During the performance of the tests, T_1 and T_4 are measured for each round, T_1 is calculated from the striking velocity of the projectile while T_4 is calculated from the maximum amplitude of the pendulum swing and the geometry of the system. Because formulation of the equations for T_4 is rather complicated only the results will be stated here.

Referring to Figure B-1,

Let a = maximum deflection of the indicator

    b = height the pendulum center of gravity rises above its
        equilibrium position

18

$$g = \text{acceleration due to gravity}$$

and

$$r = \text{effective length of the pendulum arm}$$

then

$$T_4 = M_4 gb$$

and

$$b = r - \sqrt{r^2 - a^2}$$

therefore

$$T_4 = M_4 g \left(r - \sqrt{r^2 - a^2} \right) . \qquad (B-2)$$

If the attachment of the suspension cords to the pendulum is not in the plane of the center-of-mass then the effective length of the pendulum arm will change as the pendulum swings through its maximum excursion. If d is the distance from the center-of-mass to the plane of suspension of the block, the corrected expression for T is as follows:

$$T_4 = M_4 g \left(r - \sqrt{r^2 - a^2} \right) \left(2 - \frac{1}{r} \sqrt{(r - b + d)^2 - a^2} \right)$$

(1) – EQUILIBRIUM POSITION
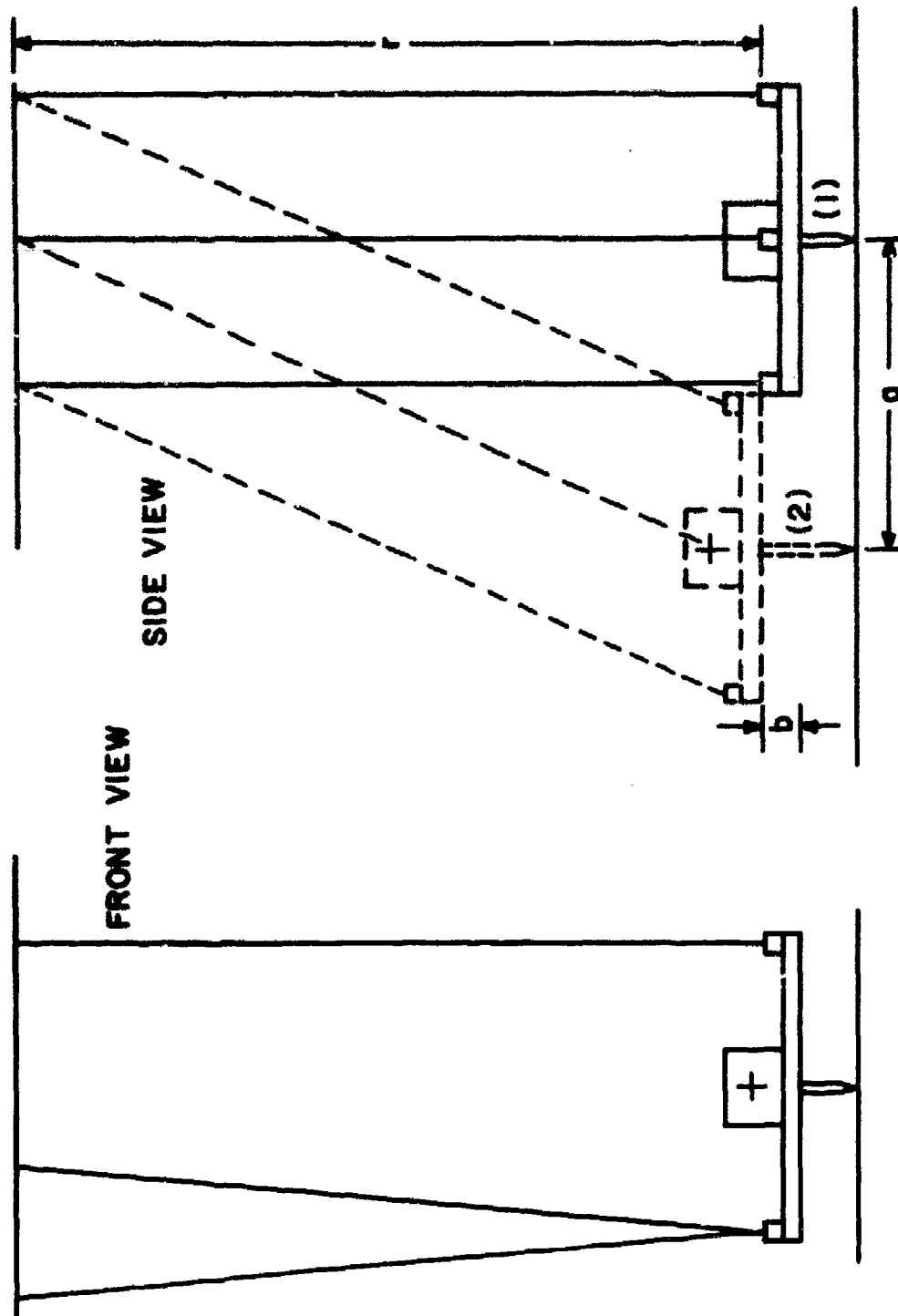(2) – MAXIMUM AMPLITUDE

SIDE VIEW

FRONT VIEW

Figure B-1. Sketch of Ballistic Pendulum and 5-Wire Suspension System

APPENDIX C

GAS GUN

A compressed gas gun is a device used to launch a projectile by the expansion of a gas behind the projectile. The primary difference between this system and the conventional cartridge loaded rifle is that in a standard rifle the gas is produced by the combustion of propellent within the chamber which is dependent upon chamber volume, burning rate, etc., while in the gas gun there is no internal formation of gases or cartridge to cartridge variations. A predetermined quantity of gas at a given pressure is allowed to expand in a constant volume expansion chamber.

Basically, the proposed system closely parallels the compressed air gun used at the Biophysics Laboratory to study the retardation of different size and shape missiles by various materials. The difference lies mainly in the two additions to this system; that is, barrel porting and projectile carrier deflector.

The projectile carrier, or sabot, is so constructed as to allow the appropriate missile to be mounted on its leading face. This allows the mounting of a missile in any desired orientation to allow accurate reproduction of a given set of initial conditions. When the sabot exits the muzzle, it strikes a deflector attached to the end of the barrel. This deflector serves two purposes; (1) it delivers a retarding impulse to the sabot separating it from the projectile and, (2) it deflects the sabot from the line of flight preventing it from striking the target.

A series of gas release ports along the barrel would be designed such that as the sabot exits the muzzle, the gage pressure within the barrel is approximately zero. The inclusion of this device produces a very desirable situation. There are no exhaust gases leaving the muzzle to perturb the missile motion near the muzzle. This means that the muzzle could be moved to within inches of the target. At such a range, for example, bullet striking yaw and velocity could be accurately reproduced. In biological studies, considerable time and money are expended

21

because of the difficulty in getting a projectile to strike a given point consistently. This would be practically eliminated using a barrel incorporating the gas release ports since aiming errors at short range would be negligible.

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*	2a. REPORT SECURITY CLASSIFICATION
U.S. Army Aberdeen Research and Development Center Ballistic Research Laboratories Aberdeen Proving Ground, Maryland 21005	Unclassified
	2b. GROUP

3. REPORT TITLE

AN INSTRUMENTED RANGE MEETING THE REQUIREMENTS OF A WOUND BALLISTICS SMALL ARMS PROGRAM

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*

William J. Bruchey, Jr. and Larry M. Sturdivan

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1968	23	0

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. RDT&E 1T062110A027	Technical Note No. 1703
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U.S. Army Materiel Command Washington, D.C. 20315

13. ABSTRACT

Instrumentation, equipment, and space requirements are outlined which would satisfy a portion of the needs of the Wound Ballistics Program of research into the terminal behavior of missiles from a variety of antipersonnel munitions (fragments, flechettes, bullets, etc.).

DD FORM **1473** REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ballistic Pendulum						
Strobe Light						
Projectile Assessment						
Wound Ballistics						
Range Facility						